Using a sample of 232×10^6 $\Upsilon(4S) \rightarrow B\bar{B}$ events collected with the BABAR detector at the PEP-II B-factory we study the decay $B^- \rightarrow [K^+\pi^-]_D K^{*-}$ where the $K^+\pi^-$ is either from a Cabibbo-favored $\bar{D}^0$ decay or doubly-suppressed D^0 decay. We measure two observables that are sensitive to the CKM angle γ; the ratio R of the charge-averaged branching fractions for the suppressed and favored decays; and the charge asymmetry A of the suppressed decays:

$$R = 0.046 \pm 0.031(stat.) \pm 0.008(syst.)$$

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A Study of $b \to c$ and $b \to u$ Interference in the Decay $B^- \to [K^+\pi^-]_D K^{*-}$

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Using a sample of 232×10^6 $\Upsilon(4S) \to B\bar{B}$ events collected with the *BABAR* detector at the PEP-II B-factory we study the decay $B^- \to [K^+\pi^-]_D K^{*-}$ where the $K^+\pi^-$ is either from a Cabibbo-favored $\bar{D}^0$ decay or doubly-suppressed D^0 decay. We measure two observables that are sensitive to the CKM angle γ; the ratio R of the charge-averaged branching fractions for the suppressed and favored decays; and the charge asymmetry A of the suppressed decays:

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An important feature of the standard model is that it accomodates CP violation through the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix V [1]. The self consistency of this mechanism can be checked by overconstraining the associated unitarity triangle [2]. In this paper we concentrate on the angle $\gamma=\arg(-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*)$ by studying B-meson decay channels where $b \to c\bar{u}s$ and $b \to u\bar{c}s$ tree amplitudes interfere. We use a technique suggested by Atwood, Dunietz and Soni [3] (ADS) where the final state $B^- \to K^+\pi^-K^*(892)^-$ can be reached from two amplitudes, $B^- \to D^0K^{*-}$ followed by the doubly-Cabibbo-suppressed decay $D^0 \to K^+\pi^-$, and $B^- \to \bar{D}^0K^{*-}$ followed by the Cabibbo-favored decay $\bar{D}^0 \to K^+\pi^-$ [4]. The size of the interference between these two amplitudes depends on the CKM angle γ as well as the *CP*-conserving relative strong phases δ_B and $-\delta_D$, and the ratios r_B and r_D of suppressed and favored amplitude magnitudes in B- ($\mathcal{A}(B^- \to \bar{D}^0K^{*-})$ and $\mathcal{A}(B^- \to D^0K^{*-})$), and D- ($\mathcal{A}(D^0 \to K^+\pi^-)$ and $\mathcal{A}(D^0 \to K^-\pi^+)$) decays. We define two measurable quantities, R and A, as follows:

$$R = \frac{\Gamma(B^- \to [K^+\pi^-]_D K^{*-}) + \Gamma(B^+ \to [K^-\pi^+]_D K^{*+})}{\Gamma(B^- \to [K^-\pi^+]_D K^{*-}) + \Gamma(B^+ \to [K^+\pi^-]_D K^{*+})},$$
$$A = \frac{\Gamma(B^- \to [K^+\pi^-]_D K^{*-}) - \Gamma(B^+ \to [K^-\pi^+]_D K^{*+})}{\Gamma(B^- \to [K^+\pi^-]_D K^{*-}) + \Gamma(B^+ \to [K^-\pi^+]_D K^{*+})}.$$

The notation $[K^+\pi^-]_D$ indicates that these particles are neutral D-meson ($D^0 or \overline{D}^0$) decay products. Neglecting the very small effect of $D^0\bar{D}^0$ mixing as justified in ref.[3], R and A are related to γ, the strong phases, r_B, and r_D by

$$R = r_D^2 + r_B^2 + 2r_Dr_B\cos(\delta_B+\delta_D)\cos\gamma, \quad (1)$$
$$A = 2r_Dr_B\sin(\delta_B+\delta_D)\sin\gamma/R. \quad (2)$$

In the above equations only r_D has been measured: $r_D^2 = 0.00362 \pm 0.00029$ [2]. Estimates for r_B are in the range $0.1 \le r_B \le 0.3$ [5]. Because there are more unknowns than measurable quantities, determining R and A does not uniquely determine γ. However, the R and A measured here can be used in combination with a similar technique proposed by Gronau, London, and Wyler (GLW) [6] to provide constraints on r_B and eventually γ. Other methods sensitive to γ [3, 7] rely on the analysis of three-body D^0 final states.

This analysis uses data collected near the $\Upsilon(4S)$ resonance with the *BABAR* detector [8] at the PEP-II storage ring. The data set consists of 211 fb^{-1} collected at the peak of the $\Upsilon(4S)$ (232×10^6 $B\bar{B}$ pairs) and 20.4 fb^{-1} 40 MeV below the resonance peak (off-peak data).

The *BABAR* detector uses a five-layer double-sided silicon vertex tracker (SVT) and a 40-layer drift chamber (DCH) to measure the trajectories of charged particles. Both the SVT and DCH are located inside a 1.5-T solenoidal magnetic field. Photons are detected by means of a CsI(Tl) crystal calorimeter also located inside the magnet. Charged particle identification is determined from information provided by a ring-imaging Cherenkov device (DIRC) in combination with ionization measurements (dE/dx) from the tracking detectors. The *BABAR* detector's response to various physics processes as well as varying beam and environmental conditions is modeled with GEANT4 [9] based software.

The decay $B^- \to D^0K^{*-}$ is reconstructed in final states where the K^{*-} decays to $K_S^0\pi^-$ followed by $K_S^0 \to \pi^+\pi^-$ and the D^0 decays into a charged kaon and pion. The analysis begins with the selection of K_S^0 candidates from oppositely charged tracks assumed to be pions. The invariant mass of the K_S^0 candidate is required to be within 10 MeV/c^2 (about three standard deviations) of the nominal K_S^0 mass [2]. The K_S^0 candidate is required to travel at least four times further than the standard deviation of its decay length. Its flight direction and decay length must be consistent with those of a K_S^0 originating from the interaction point. The momentum of a K_S^0 candidate meeting these criteria is then recalculated with a mass and vertex constraint. Next, a K_S^0 is paired with a charged track, assumed to be a pion, and the combination is constrained to come from the interaction point. The pair is kept for further study if its invariant mass is within 55 MeV/c^2 of the nominal K^* mass [2]. Finally, since the K^* from a $B^- \to D^0K^{*-}$ decay is polarized, we require $|\cos\theta_H| \ge 0.4$ where θ_H is the angle in the K^* rest frame between the daughter pion and the parent B momentum vector. This helicity-angle requirement helps discriminate B mesons from combinatorial background (mostly $e^+e^- \to q\bar{q}$ continuum events; $q \in \{u,d,s,c\}$) as the former have a $\cos^2\theta_H$ distribution while that of the

latter is uniform.

To perform the measurement, we reconstruct Cabibbo-favored $D^0 \to K^-\pi^+$ and doubly-Cabibbo-suppressed $D^0 \to K^+\pi^-$ candidates. Candidates that have an invariant mass within 18 MeV/c^2 (2.5 standard deviations) of the nominal D^0 mass [2] are kept for further study. We also select $D^0 \to K^-\pi^+\pi^0$ and $D^0 \to K^-\pi^+\pi^+\pi^-$ candidates to define various signal distributions discussed later in this paper. Loose particle identification criteria are imposed on the charged particles of all studied decay channels. Pairs of photons with a total energy greater than 200 MeV and an invariant mass in the range $125 \leq m_{\gamma\gamma} \leq 145$ MeV/c^2 are combined to form π^0 candidates that are refit, with their invariant mass constrained to the nominal π^0 mass [2]. Loose kinematic criteria are used to select the three- and four-body candidates.

Suppression of backgrounds from $e^+e^- \to q\bar{q}$ continuum events is achieved by using event shape and angular variables. Global event-shape variables are used to eliminate events with jet-like topology, a signature of $e^+e^- \to q\bar{q}$ continuum events. The thrust angle of a B-meson candidate is required to satisfy $|\cos\theta_T| \leq 0.9$, where θ_T is the angle between the thrust axis of the B-meson and that of the rest of the event.

To further reduce the $q\bar{q}$ contribution to our data sample a neural network (NN) is used. The variables used in the neural network consist of the angular moments L^0 and L^2 defined in Ref. [10], the ratio $R_2 = H_2/H_0$ of Fox-Wolfram moments [11], the χ^2 of the B-meson vertex fit, the cosine of the angle between the B candidate momentum vector and the beam axis ($\cos\theta_B$), $\cos\theta_T$ (defined above), and the cosine of the angle between a D^0 daughter momentum vector in the D^0 rest frame and the direction of the D^0 in the B-meson rest frame ($\cos\theta_H(D^0)$). The NN is trained with signal Monte Carlo events and continuum data collected below the $\Upsilon(4S)$ (off-peak data). The NN is then cross-checked with an independent set of signal Monte Carlo events. Finally, we verify that the NN has a consistent output for off-peak data and $q\bar{q}$ Monte Carlo events. The separation between signal and continuum background is shown in Fig. 1. We select candidates with neural network output above 0.8. Our event selection is optimized to minimize the statistical error on the signal yield, determined using simulated signal and background events.

We identify B-meson candidates using two nearly independent variables that take advantage of the well defined beam energy and the known kinematics of $\Upsilon(4S)$ decay: the beam-energy-substituted mass $m_{ES} = \sqrt{(s/2 + \mathbf{p}_0 \cdot \mathbf{p}_B)^2/E_0^2 - p_B^2}$ and the energy difference $\Delta E = E_B^* - \sqrt{s}/2$ where the subscripts 0 and B refer to the e^+e^- system and B-meson candidate, respectively; $\sqrt{s}$ is the e^+e^- center-of-mass (CM) energy and the asterisk labels the CM frame. The m_{ES} distribution for signal events is well represented by a Gaussian function with mean centered at the known mass of the B^- [2]

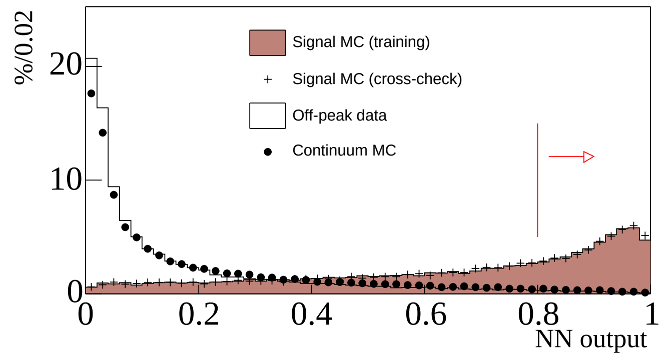

FIG. 1: The result of the neural network training and verification (see text). The training samples are shown as histograms. The signal (Monte Carlo simulation) is the shaded histogram peaking to the right; the background (off-peak data recorded 40 MeV below the resonance) is the histogram with a peak near 0. The data samples used to check the NN are overlaid as data points.The vertical bar and the arrow indicate the requirement used to select signal candidates.

and width 2.76 MeV/c^2. The ΔE distribution for signal events is described by a Gaussian function centered at zero with a width that varies from 11 to 13 MeV among the different final states. These quantities are measured in the data from $B^- \to D^0K^{*-}$ with Cabibbo-favored D^0 decays. For this analysis signal events must satisfy $|\Delta E| \leq 25$ MeV.

The efficiency to detect a $B^- \to D^0K^{*-}$ signal event where $D^0 \to K\pi$, after all criteria are imposed, is (9.6±0.1)%. This efficiency is the same for $D^0 \to K^-\pi^+$ and $D^0 \to K^+\pi^-$. There are multiple candidates in 12% of the events. In such cases the candidate with the smallest $|\Delta E|$ is selected for further study. According to Monte Carlo simulation, this is the correct candidate 88% of the time.

We study various potential sources of background using a combination of Monte Carlo simulation and data events. Two sources of background are identified in large samples of simulated $B\bar{B}$ events. One source is $D^0K^0_S\pi^-$ production where the $K^0_S\pi^-$ is non resonant and has an invariant mass in the K^{*-} mass window. This background is discussed later in this paper. The second background (peaking background) includes instances where a favored decay (i.e. $B^- \to [K^-\pi^+]_D K^{*-}$) contributes to fake candidates for the suppressed decay (i.e., $B^+ \to [K^-\pi^+]_D K^{*+}$). The most common way for this to occur is for a π^+ from the rest of the event to be substituted for the π^- in the K^{*-} candidate. Other sources of peaking background include double particle-identification failure in signal events that results in $D^0 \to K^-\pi^+$ being reconstructed as $D^0 \to \pi^-K^+$, or the kaon from the D^0 being interchanged with the charged pion from the K^*. From a detailed Monte Carlo study the total size of this background is estimated to be 1.4±0.2 events. We also

verify with the Monte Carlo simulation that the charmless decays with the same final state as the signal (e.g., $B^- \to K^{*-}K^-\pi^+$) are not a significant background for this analysis.

Signal yields are determined from an unbinned extended maximum likelihood fit to the m_{ES} distribution in the range $m_{ES} \geq 5.2$ GeV/c^2. A Gaussian function ($\mathcal{G}$) is used to describe all signal shapes while the combinatorial background is modeled with an ARGUS [12] threshold function($\mathcal{A}$). This function's shape is determined by one parameter ξ while a second parameter, $\mathrm{E_{max}} = \sqrt{s}/2$, (fixed at 5.2901 GeV/$c^2$) is the maximum mass for pair-produced B-mesons given the collider beams energies. For a probability distribution function (PDF) we use $a \cdot \mathcal{A} + b \cdot \mathcal{G}$ where a is the number of background events and b the number of signal events. We correct b for the peaking background previously discussed (1.4±0.2 events). The mean and width of $\mathcal{G}$ and the value of ξ are determined by an initial fit to all $B^- \to D^0K^{*-}$ candidates where the D^0 decays into the Cabibbo-favored channels $K^-\pi^+$, $K^-\pi^+\pi^0$, and $K^-\pi^+\pi^+\pi^-$.

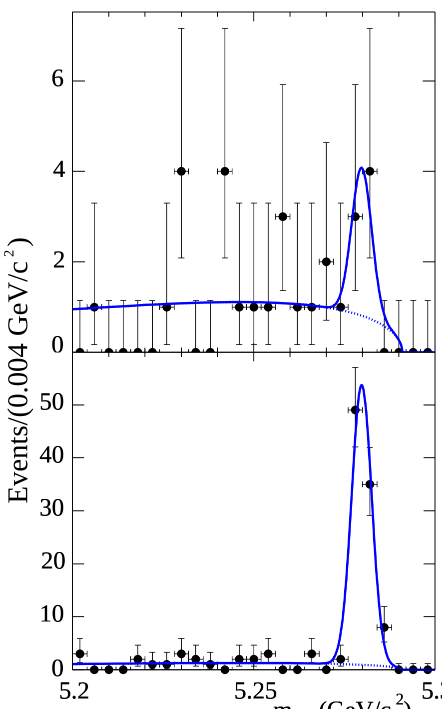

FIG. 2: Distributions of m_{ES} for the wrong-sign (top) and right-sign (bottom) decays. These decay categories are defined in the text. The curves result from a simultaneous fit to these distributions with identical PDFs for both samples.

In Fig. 2 we show the results of a simultaneous fit to $B^- \to [K^+\pi^-]_D K^{*-}$ and $B^- \to [K^-\pi^+]_D K^{*-}$ candidates that satisfy all selection criteria. We call wrong- (right-) sign decays those where the K^* and the kaon

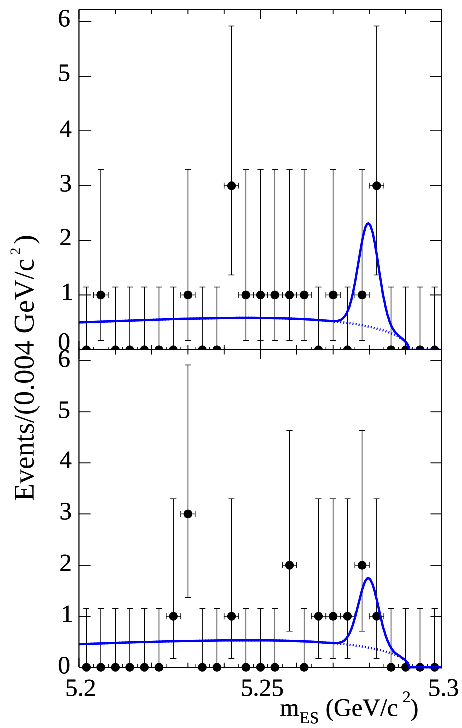

FIG. 3: Result of a simultaneous fit to the wrong-sign and right-sign m_{ES} distributions with identical PDFs for both samples. Here the wrong-sign sample shown in the top plot of Fig. 2 is split by charge to measure A. The upper plot shows the m_{ES} distribution of the $B^+ \to [K^-\pi^+]_D K^{*+}$ decays while the lower plot presents the same for the $B^- \to [K^+\pi^-]_D K^{*-}$ decays. The curves are the results of the fit.

have opposite (same) strangeness. It is in the wrong-sign decays that the interference we study takes place. Therefore in Fig. 3 we display the same fit separately for the wrong-sign decays of the B^+ and the B^- mesons. The results of the maximum likelihood fit are $R = 0.046 \pm 0.031$, $A = -0.22 \pm 0.61$, and 91.2 ± 9.7 $B^- \to [K^-\pi^+]_D K^{*-}$ right-sign events. Expressed in terms of the wrong-sign yield, the fit result is 4.2 ± 2.8 wrong-sign events. The errors are statistical only. The correlation between R and A is insignificant.

In Table I we summarize the systematic errors relevant to this analysis. Since both R and A are ratios of similar quantities most potential sources of systematic errors cancel. The estimate for the detection-efficiency asymmetry is obtained from a sample of $B^- \to D^0\pi^-$ events. Here a charge asymmetry of $A_{ch} = (-1.9 \pm 0.8)\%$ is measured. We add linearly the central value and one-standard deviation in the most conservative direction to assign a systematic error of $\delta A_{ch} = \pm 0.027$ to the A measurement. To a good approximation the systematic error in R due to this source can be shown to be given by $\delta R = R \cdot A \cdot \delta A_{ch}$, with A the previously determined

central value.

To estimate the systematic uncertainty on A and R due to the peaking background, we use the statistical uncertainty on this quantity, ± 0.2 events. With approximately 4 $B^- \to [K^+\pi^-]_D K^{*-}$ events and 90 $B^- \to [K^-\pi^+]_D K^{*-}$ events this source contributes ± 0.002 and ± 0.043 to the systematic errors on R and A, respectively.

To account for the non resonant $K^0_S\pi^-$ pairs in the K^* mass range we study a model that incorporates S-wave pairs in both the $b \to c\bar{u}s$ and $b \to u\bar{c}s$ amplitudes. It is expected that higher order partial waves do not contribute. The amount of S-wave present in the favored $b \to c\bar{u}s$ amplitude is determined directly from the data by examining the angular distribution of the $K^0_S\pi$ system in the K^* mass region. To estimate the systematic errors due to this source we vary all strong phases within 2π and calculate the maximum deviation between the S-wave model and the expectation if there were no non resonant contribution for both R (Eq. 1) and A (Eq. 2). The result of this study is given in Table I.

In the fit to the m_{ES} distribution we use parameters determined from an initial fit that includes $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$ and $K^-\pi^+\pi^+\pi^-$ candidates. We repeat the fit using parameters from each individual D^0 decay channel and calculate a contribution to the systematic error from the observed variations in R and A. We also vary $\mathrm{E}_{\max}$ by $\pm 2\,\mathrm{MeV}$, refit and add the maximum shifts in R and A to the previously described contribution to obtain the systematic error associated with the shape of the m_{ES} distribution. After adding in quadrature the individual systematic error contributions listed in Table I, we find:

$$
\begin{aligned}
R &= 0.046 \pm 0.031(stat.) \pm 0.008(syst.), \\
A &= -0.22 \pm 0.61(stat.) \pm 0.17(syst.).
\end{aligned}
$$

We also quote the results in terms of two other variables:

$$
\begin{aligned}
R\,(1+A) &= 0.036 \pm 0.042 \pm 0.010, \\
R\,(1-A) &= 0.056 \pm 0.045 \pm 0.012.
\end{aligned}
$$

They may be of use in combining γ-sensitive measurements from the GLW and ADS methods, and the analyses exploiting three-body D^0 decays. The effect of the non resonant $K^0_S\pi^-$ background gives the dominant contribution to the systematic uncertainties, ± 0.009 on both quantities.

In order to extract information on r_B and γ we combine the above measurements of R and A with measurements of similar quantities, $R_{CP\pm}$, $A_{CP\pm}$, from $B \to D^0_{CP}K^{*-}$ [13] using the method suggested in Ref. [6], in which the D^0 decays to CP eigenstates are exploited. A frequentist statistical approach [14] is used. A χ^2 is formed from the differences between the measured and theoretical values, and the covariance matrix of the six measured variables. We restrict r_B to values between 0 and 1.3 and allow γ to vary between 0 and 180° for all possible values of $(\delta_B + \delta_D)$ between 0 and 360°. We call $\chi^2_{min}(= 1.4)$ the minimum χ^2 for the whole parameter space. We then scan the r_B range: for each value of r_B we minimize the χ^2 across the reduced parameter space (where r_B is fixed), and find χ^2_m. We use $\Delta\chi^2 = \chi^2_m - \chi^2_{min}$ to compute the confidence level of r_B assuming Gaussian uncertainties. Figure 4 shows the confidence level resulting from this r_B scan. Combining the ADS and GLW results we find

$$r_B = 0.28^{+0.06}_{-0.10}.$$

In a similar fashion, we show the confidence level for the γ scan in Fig. 5. The interval $75° \leq \gamma \leq 105°$ is disfavored at the two-standard deviation level.

In summary we present the first measurements of yields from $B^- \to [K^+\pi^-]_D K^{*-}$ decays. By exploring the behavior of the likelihood function close to its maximum, we determine that the statistical significance for R to differ from zero is at the two-standard deviation level. As seen on Fig. 4, this (ADS) result narrows the allowed r_B range previously obtained with the GLW method [13]. The constraint the ADS method provides on γ is weak

TABLE I: Summary of systematic uncertainties.

Source	δR	δA
Detection asymmetry	± 0.0003	± 0.027
Peaking background	± 0.002	± 0.043
Non resonant $K^0_S\pi^-$ background	± 0.0073	± 0.126
Shape of m_{ES} distribution	± 0.0023	± 0.108
Total systematic error	± 0.008	± 0.174

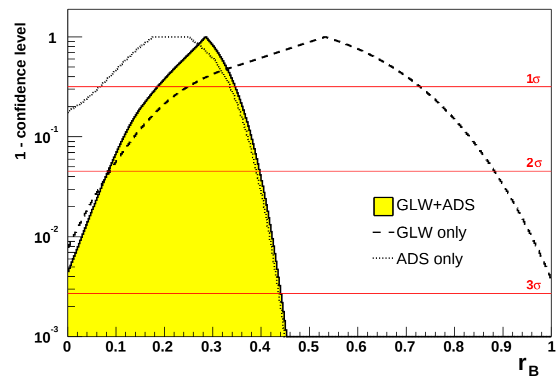

FIG. 4: Constraints on r_B. The *BABAR* $B^- \to D_{CP}K^{*-}$ (GLW) [13] result is combined with this analysis. The dashed (dotted) curve shows 1 minus the confidence level to exclude the abscissa-value as a function of r_B derived from the GLW (ADS) only measurements. When both the GLW and ADS results are combined the curve above the shaded area is obtained. Horizontal lines show the exclusion limits at the 1, 2 and 3 standard deviation levels.

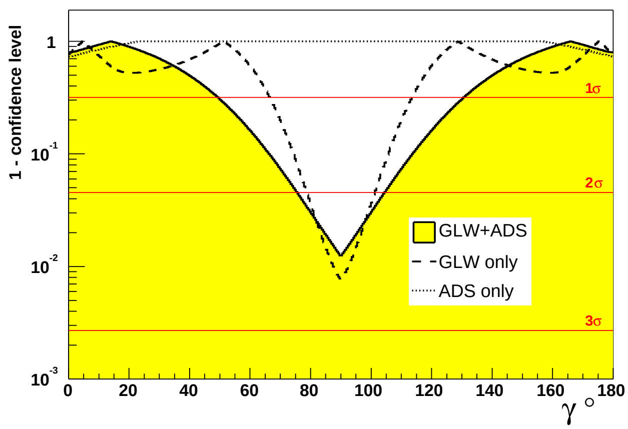

FIG. 5: 1 minus exclusion confidence level curve for γ obtained from the *BABAR* $B^- \to D_{CP} K^{*-}$ (GLW) result combined with this analysis. The graphical conventions are described in the caption of Fig. 4.

with the present data sample.

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